Acta Mineralogica-Petrographica, Szeged, XXIV/1, 137—147, 1979

GEOTHERMAL INHOMOGENEITY IN THE HUNGARIAN GREAT PLAIN (PANNONIAN BASIN)

L. VÖLGYI

ABSTRACT

Investigations tried to analyze the geothermal conditions of the Pannonian Basin by processing the thermal data obtained from deep boreholes and to explore in detail the measures of inhomogeneities and tendencies of changes.

In a global sense the Pannonian Basin as a crustal structural unit can be characterized by a gradient corresponding to the terrestrial geothermal mean value. On the basis of regional comparison, however, considerable inhomogeneity occurs characterized by higher minima and high maxima approaching the world average. Based on statistic evaluations, the extreme values of spatial changes show changes of geothermal gradient of 4 to 8 °C/100 m as a function of the geographical situation and of the depth. The reliable isotherm calculations have shown similar inhomogeneity. The measure of vertical inhomogeneity is 4.2—6.8 °C/100 m being valid of the depth interval of 650 to 2860 m, in case of the isotherms calculated to 60—140 °C.

Studying the change of geothermal gradient as a function of depth four basic types can be distinguished:

1) the gradient increasing with depth, this can be approached by a straight line,
2) the gradient increasing at the beginning and decreasing later with depth, this can be approached by a sine wave,
3) the mixed gradient type of uncertain evaluation,
4) special gradients of obvious local anomalies.

Having studied the areas explored by deep-bores "hot-sites" lying in minimal depth as well as "cold-sites" lying in maximal depth could be determined. The result of processing of geothermal data, which can be generalized is that the value of the average geothermal gradient unambiguously decreases in sedimentary sequence parallel with increasing depth and concerning the depth interval between 100 and 5500 m this value is 7.0—4.0 °C/100 m.

INTRODUCTION

The endogene heat plays decisive role in the "internal life" of the earth since its origin to the recent. The views on the origin of this endogene heat can be divided into two groups. According to one of the research groups the earth preserved a part of the cosmic heat of the high-temperature origin but during its evolution it gradually cools and shrinks. The members of the other group (mostly the followers of the theory of condensation from cosmic dust) pronounce for the continuous heat generation. Estimations concerning the heat resources of the earth show recently rather diverse values. It seems to be probable that the heat quantity which can be derived from radioactive decay (43.34×10^{16} cal/hours) amounts to amount 24-fold of the emitted heat quantity (1.8×10^{16} cal/hours). This latter value supports the followers of heating, i.e. of the earth's expansion. Be, however, the recent balance of thermal budget of the earth either positive or negative, it can be stated that none of the theories could avoid the problem of terrestrial heat. This in itself is also the evidence of the significance of geothermics in several fields of geology.

THE GLOBAL THERMAL FIELD OF THE EARTH

Taking in general the geothermal situation of the earth, it follows from the second principle of thermodynamics that between the sites of different temperatures thermal transport is started from the warmer towards the cooler parts.

As to the investigations the global thermal field of the earth can be regarded to be stationary when taking the recent of the earth's history. The value of the earth's heat flux is estimated to be 1.5×10^{-6} cal/cm^2, in general.

Disregarding the insolation and eradiation phenomena the internal thermal field of the earth endures distortion partly due to the "heat source", partly due to the inhomogeneities of thermal conduction.

Regional (megatectonic) and local reasons may be responsible for the distortion of the terrestrial thermal field. The former will be discussed later in relation with the Pannonian Basin. In general, it can be said that the distribution of the isotherms of the terrestrial thermal field and of the main streamlines is considerably influenced by the spatial configuration of the rocks of different thermal conduction in the investigated area, resp., depth interval. In local sense, the "heat sources" (heat-producers) of physical sense play extraordinarily significant role. In addition to the well-known heat-producing geological processes, e.g. radioactivity or ore oxidation, the role of abyssal water is of more general validity especially in Hungarian conditions. As a result of the great specific heat and of the relatively low thermal conductivity of rocks the water flowing in subsurface regions keeps its basic temperature, thus, in the nature the temperature of water often differs from that of its environment (hot waters, karst water).

In connection with the so-called "depth thermal disturbance" generating under deep-geological conditions it is worthy to mention some physical facts. To the realization of thermal equilibrium, i.e. to the formation of stationary field theoretically infinite time is needed, after the thermodynamic calculations. When investigating the date of the stage approaching this state to 90 percent, a significant time value (about 10 million years) is obtained also in geological sense if e.g. deriving the site of thermal disturbance from the depth of the Moho-surface [STEGENA, L., SALÁT, P., 1972].

GEOTHERMAL SITUATION OF THE PANNONIAN BASIN

The geothermal conditions of a geological unit, area or region can be characterized most clearly by the average geothermal gradient or by its invert. As it has been stated in my previous work [VÖLGYI, L., 1978] on the basis of several hundred corrected temperature data deriving from the boreholes of the Great Plain constituting the major part of Hungary's area, the extreme values and averages of the geothermal gradient (resp. invert) are as follows:

extreme values: 4—8 °C/100 m = 25 – 12.5 m/°C
average values: 5.5 °C/100 m = 18 m/°C

Numerous authors tried to find relationship between the geological structure and the geothermal gradient. On the basis of the most frequent data of the rather different evaluations the following average values could be determined.

Average of continents (tabular and folded areas):
2.03 °C/100 m = 33 m/°C

Areas of ancient shields:

0.8 °C/100 m = 125 m/°C

Volcanic areas, young geosynclines:

9.7 °C/100 m = 10.3 m/°C

Shelves (mostly Scotland):

2.2 °C/100 m = 45.4 m/°C

Super-deep boreholes (USA, Soviet Union):

1.8 – 3.1 °C/100 m = 56.5 – 32.2 m/°C

On the basis of some data of Hungarian deep boreholes the decrease of the geothermal gradient is also probable:

3.8 – 4.0 °C/100 m = 26.3 – 25.0 m/°C

Thus, considering the average extreme values of the crustal-structural types of the earth, i.e. the minimal 0.8 and the maximal 9.7 °C/100 m geothermal gradient, it can be stated that the Pannonian Basin represents nearly exactly the mean value.

The Pannonian Basin is a young geosyncline which is surrounded by crust parts of continental folded structure. Thus, in regional environmental sense it is a combined type, because the average of 5.5 °C/100 m exceeds the continental average (3.03 °C/100 m) but does not reach the world maxima of volcanic areas and young geosynclines.

The considerable deviation of the extreme values relates to large-scale local changes and provides a fair basis to real interpretation. The minimal extreme value is higher than the continental average which obviously proves the relative "hot" crustal position. The fact, however, that the maximal extreme value nearly reaches the maxima of 9.7 °C/100 m of the volcanic areas, is in clear relationship with the real geological conditions.

CRUSTAL-STRUCTURAL BACKGROUND OF THE DISTORTION OF THE TERRESTRIAL THERMAL FIELD IN HUNGARY

Based on areal comparative studies it can be accepted as an evidence that the Pannonian Basin possesses a higher heat flow value as compared to its environment [STEGENA, 1973]. According to him the geoisotherms of 1 km indicate 50—70 °C in Hungary's area while in the surroundings these amount only to 30—40 °C. Thus, the area of Hungary is a "relative geothermal maximum" with high heat flux values.

When evaluating the regional geological situation the search for geothermal reasons is to be carried out only down to the lower boundary of the crust, i.e. to the surface of the Moho-discontinuity. On the basis of the Carpatho-Dinaride crust-surveying seismic profile the crustal thickness below the Pannonian Basin amounts only to 26 km [MITUCH, E., POSGAY, K., 1972]. Along this profile the change of the thickness ratios of the upper crust (granite velocity zone) and of the lower crust (basalt velocity zone) is remarkable. In Hungary's area the basalt-zone is extraordinarily thinned (5 to 8 km thickness). This indicates the approach of the Moho-surface to the earth's surface which is produced by isostatic compensation of the average subsidence of 3000 m of the Pannonian. This phenomenon is considered by STEGENA *et al.*, [1975], to be a mantle diapir which has been generated by the subduction connected to the surrounding mountains. The subduction zones are dealt with by SZÁDECZKY-KARDOSS, E., [1973]. The subduction zones reported by him coincide with the megatectonic lines known so far. It is without doubt that the zonal arrangement of the hydrocarbon and carbon-dioxide deposits joins the directions of the megatectonic lines. The thermal disturbance, however, prevails in the Pannonian Basin on a regional scale. The tectonic lines may prove only local anomalies at least.

Investigating the velocity of heat flow in harmony with the geological events it seems to be probable that the recent upper crustal relative geothermal anomaly is produced by the thermal disturbance followed at the Pannonian-Miocene boundary. In accordance with STEGENA, L., when studying the origin of heat surplus the decisive significance of heat transport (convective transport) should be regarded a regional factor produced by upward directed material transport.

The statement of SVETZOV, P. P., [1974] is remarkable, i.e. concerning the anomalously high temperatures occurring in the Piedmont and Intramontane Basins of the Alpine folded zone. Accordingly, this thermal anomaly can not be always sufficiently explained only by the endogene heat of the earth. In these basins the thick sequences of clayey and fine-detrital rocks being in state of compaction are believed to by supplementary heat flow sources. "This type of strate forms a heat-shade promoting the accumulation of heat in the "nest" below the shade".

The vertical heat transporting role of the volcanic activity proceeded in the Miocene and Pannonian is without doubt. Further, it is obvious that only a part of heat deriving from volcanic activity was emitted to the earth's atmosphere. Recently, by means of vitrinite reflectance measurements it can be evidenced that in the surroundings of the Miocene volcanites the paleo-temperature of the Early Pannonian was considerably higher than in our days. Since that time these formations lie in a gradually subsiding basin, but relatively these are "cooled". This is possible only if the heat surplus of volcanic origin was transferred into the sedimentary sequence and when spreading it an average compensation temperature was produced in the Pannonian sediments.

As to the author's opinion the convective heat transporting activity of the upward flowing hot waters deriving from great depths through fractures and fissures should also be considered a similar supplementary heat flow source. The role and significance of the water flows in basins were always emphasized by Hungarian experts.

EVIDENCES OF GEOTHERMAL INHOMOGENEITY

In this paper the data deriving from the area east of the Danube and from (hydrocarbon prospecting and exploring) deep-bores were used. In the previous work [VÖLGYI, L., 1978] the measures and tendencies of abyssal thermal changes were studied and more considerable inhomogeneity was obtained than expected before.

When plotting the data of geothermal gradient as a function of depth isotherm curves can be constructed which provide the theoretical depth-distribution function of a temperature value. This, however, bears practical significance if correctly determined gradients and depth data are used.

Corrected isotherm calculations

The calculations of isotherms was corrected so that less but more reliable basic data were taken into account. In favour of this only the measurement data were used which approached the temperature value of the isotherm to be computed to ± 10 °C. In this way the number of reliable data decreased from 450 to 165 but this made possible to carry out linear interpoiation within a depth interval of ± 200 m.

The procedure has been as follows:

t = measured temperature, °C, within the interval of ± 10 °C,

t_i = isotherm value (°C),

i =60, 80, 100, 120, 140,

M =depth of temperature measurement (m),

M_i=calculated depth of the isotherm *i* in the geological formation of definite age of the given area.

Consequently:

$$M_i = \frac{M \cdot t_i}{t}.$$

The distribution in depth of the calculated isotherms are shown in *Fig. 1.* The comprehensive evaluation of this gives the following result.

According to the data, above 140 °C the uncertainties are great. This is caused by the fact that the average depth of the boreholes varies around 2600 m, thus data of sufficient quantity are available only to this depth (due to the accuracy criteria).

It can be demonstrated that the depth variance of the isotherms between 60 and 120 °C is of an order of magnitude of several hundred metres as it can be seen in Table 1:

TABLE 1

Isotherm (C)	Depth limits (m)	Average depth (m)	M_z (m)
60	650—1280	965	630
80	980—1680	1330	700
100	1320—2080	1700	760
120	1660—2500	2080	840
140	2000—2860	2430	860

M_z = depth interval.

Average and extreme values of geothermal gradients

To control the previous statistic work the calculations of geothermal gradients following from the isotherm calculations was also carried out.

The result is shown in Table 2:

TABLE 2

Isotherm (°C)	Isothermal gradient* (°C/100 m) Interval	Average values	Invert (m/°C)
60	7.54—3.83	5.07	19.69
80	7.04—4.11	5.18	19.27
100	6.74—4.28	5.23	19.10
120	6.56—4.36	5.24	19.08
140	6.45—4.51	5.30	18.84
Average to 60—140:	4.22—6.86	5.20	19.19

* taking 11 °C near-surface temperature.

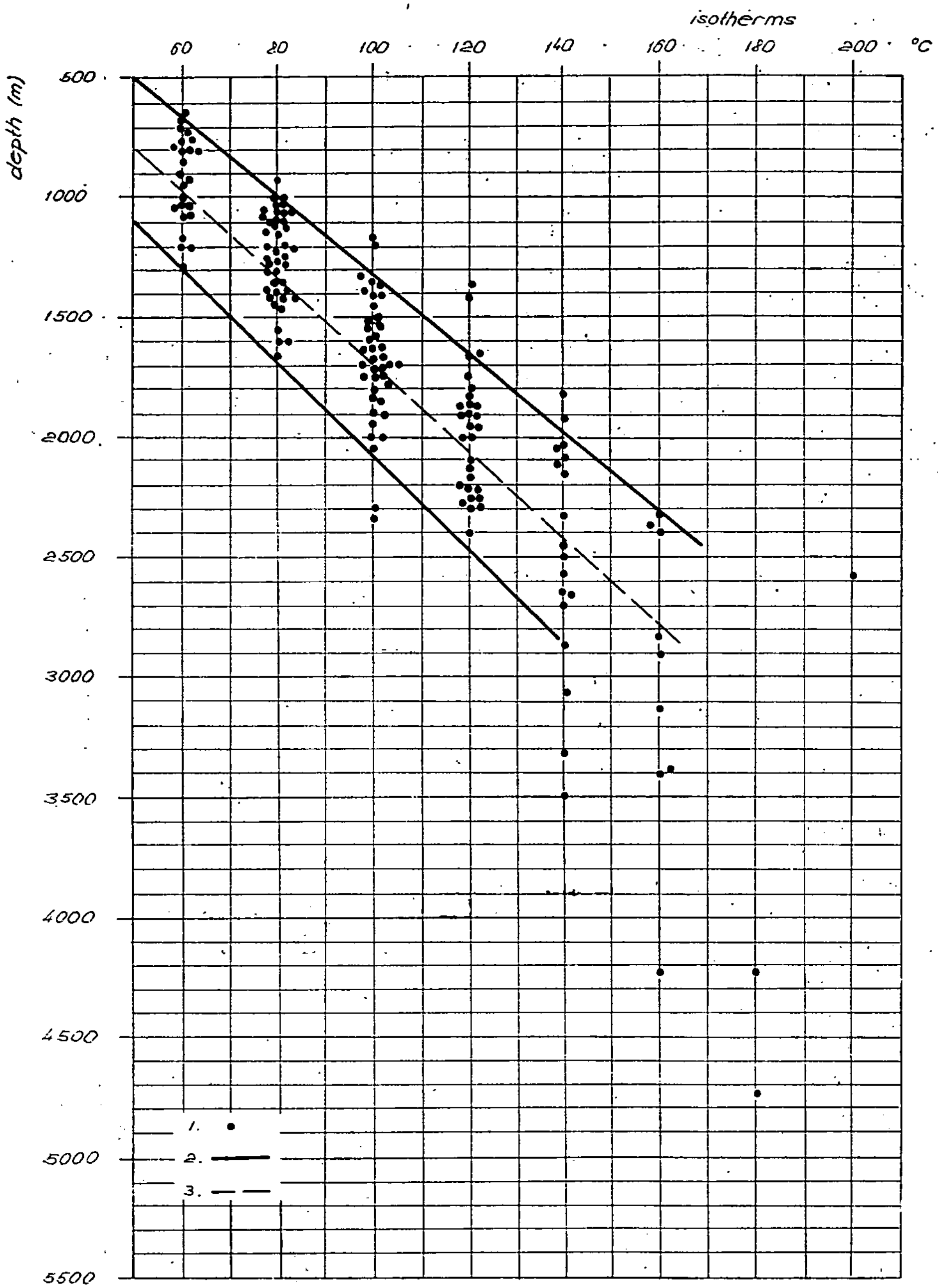

Fig. 1. Distribution in depth of the calculated isotherms. 1) calculated depth of isotherms; — 2) extreme values of gradients; — 3) average gradient.

Comparison of the average and extreme values between the statistic and corrected (i.e. computed from isotherms) methods is given in Table 3:

TABLE 3

Method	Geothermal gradient (°C/100 m) Extreme	Average	Invert (m/°C)
statistic	4.0—8.0	5.5	18.2
corrected	4.2—6.8	5.2	19.2

The measure of vertical inhomogeneity of the Great Plain is 4.2—6.8 °C/100 m according to the corrected geothermal gradient calculations. It is valid of the intervals of 60 to 140 °C and 650 to 2860 m.

GEOTHERMAL REGION TYPES IN THE GREAT PLAIN

In this part the investigation results carried out in connection with local change of the geothermal gradients will be discussed. On the basis of the collected data two fundamentally differing types will be introduced by means of several concrete instances.

E.g. "hot-sites" lying in minimal depth:

Mezőhegyes	in 457 m	58 °C
	in 1095 m	90 °C
Tótkomlós	in 762 m	68 °C
	in 1008 m	86 °C
	in 1486 m	121 °C
	in 2190 m	150 °C
Hunya	in 3925 m	203 °C

E.g. "cold-sites" lying in maximal depths:

Nagyecsed	in 1174 m	55 °C
Cegléd	in 1389 m	92 °C
Mindszent	in 2472 m	107 °C
Furta	in 2341 m	100 °C
Algyő	in 1106 m	58 °C
	in 1506 m	75 °C
	in 2054 m	107 °C
	in 2423 m	126 °C
	in 2545 m	132 °C
	in 3196 m	163 °C
Makó	in 3500 m	147 °C
	in 4095 m	173 °C
Hódmezővásárhely	in 4790 m	181 °C
	in 5418 m	203 °C

These few examples also indicate that how relative are the "cold" and "hot" notions since the location bears significance only as a function of depth. In evaluation the space coordinates should be taken into account.

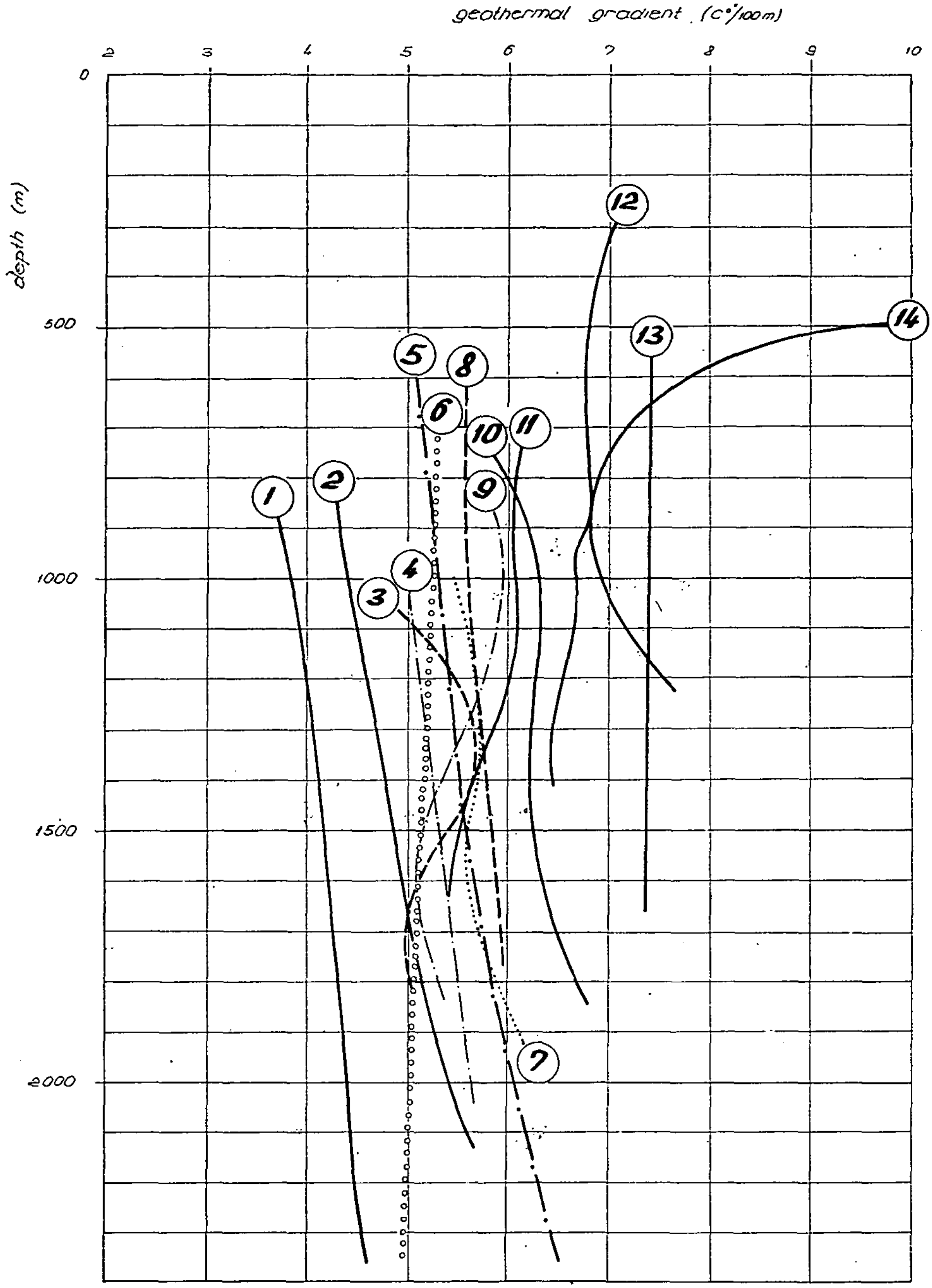

Fig. 2. Local changes of the geothermal gradient (Great Plain). — Names of exploratory wells № 1—14 see in the text

In everyday sense, the area characterized by hot waters from small depths is called "hot-site" but in absolute value the temperature of 203 °C is qualified also as "cold-site" when it is below the depth of 5400 m.

Types of geothermal gradients

The change of the geothermal gradient as a function of site and depth is shown in the figure of complex change of geothermal gradient *(Fig. 2)*. This shows the areal average run of the temperature gradients of 14 regions of the Great Plain. The result is certainly astonishing. It is clear that a given gradient value is rather meaningless if one tries to know the real situation.

In the 14 areas constant gradient is found only in one case. The gradient of all the other areas are changing as a function of depth, in all possible varieties.

Gradients increasing and decreasing as a function of depth are found, as well as tendencies of repetition or completely turn also occur. These concrete changes of geothermal gradients averaged to each regions call the attention to the search for the local geological reasons. The gradient types are as follows:

(a) *Gradient increasing with depth* (this can be approached by a straight line). The representative areas (number of lines in the figure in brackets):
- Algyő (1)
- Kiskunhalas (2)
- Szank (4)
- Üllés (5)
- Kaszaper (8)
- Pusztaföldvár (10; not typical)

(b) *Gradient first increasing then decreasing with depth* (this can be approached by a sine-wave):
- Kisújszállás (3)
- Hajdúszoboszló (11)
- Kunmadaras (7)
- Szandaszőlős (9)

(c) *Mixed gradient type of uncertain evaluation:*
- Endrőd (6) — decreasing tendency
- Ebes (12) — curve of decreasing tendency

(d) *Special gradients of obvious local anomalies:*
- Tótkomlós (13) — independent of depth, high constant gradient,
- Mezőhegyes (14) — gradient suddenly decreasing along a hemicircle then increasing with depth.

TENDENCIES OF VERTICAL INHOMOGENEITY IN GREATER DEPTHS

The results of particular investigations introduced in the previous chapters fairly represent the conditions of geothermal gradients in the sedimentary sequence of the Pannonian Basin down to about 2500—3000 metres depth but do not provide information for greater depths. Thus, though the number of data is insufficient, it is expedient to investigate the change of geothermal gradient as a function of depth using all the data available *(Fig. 3)*.

When determining the minimal — average — maximal tendency of changes of the geothermal gradient as a function of depths by means of graphic plotting, according to *Fig. 3* the approximate values shown in Table 4 will be obtained:

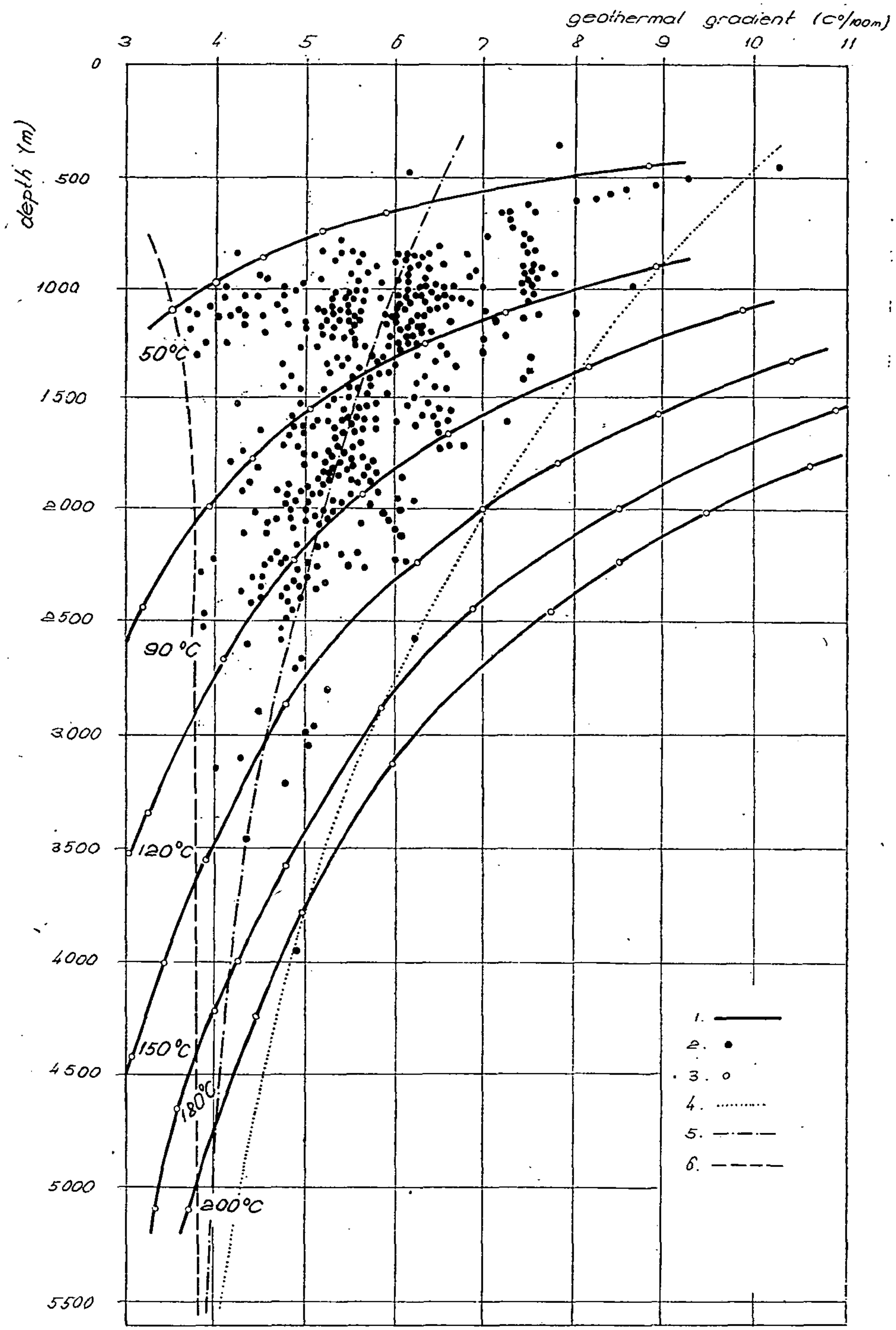
geothermal gradient (C°/100m)
3
4
5
6
7
8
9
10
11
depth (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
50°C
90°C
120°C
150°C
180°C
200°C
1.
2.
3.
4.
5.
6.

TABLE 4

Isotherm	Depth — Temperature gradient					
	Minimal		Average		Maximal	
°C	M	°C/100 m	M	°C/100 m	M	°C/100 m
50	1100	3.5	600	6.4	400	10.0
90	2100	3.7	1400	5.7	900	8.9
120	2900	3.75	2150	5.1	1400	8.0
150	3600	3.8	3000	4.7	2000	7.0
180	4400	3.8	4000	4.25	2900	6.0
200	>5000	3.8	4700	4.15	3700	5.0

It can be stated that with increasing depth

— the minimal value hardly changes (3.5—3.8);

— the maximal value considerably decreases (10.0—5.0);

— the average value unambiguously decreases.

The decrease of the average geothermal gradient with increasing depth is believed a tendency, the fact of which is without doubt.

The measure of decrease of the average geothermal gradient determined by author is 7.0—4.0 °C/100 m concerning the depth interval of 100 to 5500 m.

The reasons of this phenomenon should be searched by means of further particular investigations. To elucidate this problem it would be advantageous to investigate the role of convection flows and the thermal conduction coefficient of the terrestrial heat flows.

REFERENCES

MITUCH, E., POSGAY, K. [1972]: Hungary. In: "The crustal structure of Central and Southeastern Europe based on the results of explosion Seismology (ed.: SZÉNÁS, GY.). Geophys. Trans. Spec. Edit., Budapest, 118—130.

STEGENA, L., SALÁT, P. [1972]: A mélyfúrásokkal kapcsolatos geotermikus kutatások alapösszefüggései (Basic relationships of geothermal researches connected to deep-bores). — Publication of the MTESZ — Magyar Geofizikusok Egyesülete.

STEGENA, L. [1973]: A Pannon-medence kainozóos evolúciója (Cenozoic evolution of the Pannonian Basin). — Geonómia és Bányászat, **6**, 1—4.

STEGENA, L. *et al.* [1975]: A Pannon-medence későkainozóos fejlődése (Late Cenozoic evolution of the Pannonian Basin). — Földtani Közl., **105**, 2.

SVETZOV, P. P. [1974]: Geothermal conditions of Mesozoic and Cainozoic hydrocarbon-bearing basins (in Russian), Nauka, USSR.

SZÁDECZKY-KARDOSS, E. [1973]: A Kárpát-pannón terület szubdukciós övezetei (Subduction zones of the Carpatho-Pannonian area). — Földtani Közl., **103**, 3—4.

VÖLGYI, L. [1978]: The role of geothermal conditions of Hungary in hydrocarbon prospection. — Acta Geol. Acad. Sci. Hung., Tom. **21**, 1—2.

Manuscript received, November 20, 1978

DR. LÁSZLÓ VÖLGYI
Petroleum Exploring Enterprise,
H-5000 Szolnok, Munkásőr u. 43.
Hungary

Fig. 3. Change of the geothermal gradient as a function of depth (data of the Great Plain). — 1) isotherms, being fundamental from the point of view of hydrocarbons, — 2) measured data, — 3) points of curve construction, — 4) maximal gradient, — 5) average gradient, — 6) minimal gradient